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GUIDE FOR INSULATION CO-ORDINATION WITHIN LOW-VOLTAGE SYSTEMS

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GUIDE FOR INSULATION CO-ORDINATION WITHIN LOW-VOLTAGE SYSTEMS

0. FOREWORD

0.1 This Special Publication was adopted by the Indian Standards Institution on 23 February 1987, after the draft finalized by the High Voltage Techniques Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This guide deals with the principles which govern insulation coordination in low voltage installations. It also provides guidance for specifying creepage distances and clearances in air for low-voltage equipment in such a manner that insulation coordination in the installation becomes possible, and that coordination between different apparatus used in the same or different situations is rationalized. Further, the standard also provides data to the relevant equipment committees dealing with low voltage equipment to specify internal insulation.

0.3 Overvoltages in LV systems originate from the following causes:

a) load fluctuations,
b) switching operations, resonances and faults, and
c) lightening discharges.

In the past, adequate attention was not given to the nature and effects of these overvoltages. However increased application of miniaturized electronics in consumer and industrial products has focussed attention on the need to study overvoltage phenomena in LV systems. These overvoltages also affect common LV consumer installations and equipment therein such as motors, switchgear, appliances, lamps, energy meters and luminaires.

0.4 Within the country, the various utilities and manufacturers have come across failures of LV equipment identified above, altributable to overvoltages. Even though exhaustive studies as would be required on an issue like this have not been carried out, experts are of the view that there is a need for proving through tests, the adequacy of design of these equipment to withstand overvoltages. Unless all the issues involved in insulation coordination are adequately considered and systematically dealt with, it is likely that over-insulated designs, would result thus making the equipment expensive and not necessarily reliable.

0.5 Insulation co-ordination can only be achieved if transient overvoltages are controlled to specified levels. Numerous types of overvoltage control means are available, but in addition to the special devices for this purpose, many of the existing clearances actually serve as voltage limiting means by flashing over without consequential fault current, when the energy in the transient overvoltage wave is too low to ionize the gap sufficiently to initiate a fault current. In this Guide it was assumed that such means exist in the system, and therefore, controlled voltage systems are the basis for the standardized values of impulse withstand voltage. For the purpose of insulation co-ordination it is, therefore, absolutely essential to establish standardized impulse voltage levels.

0.6 The High Voltage Techniques Sectional Committee, ETDC 19, which had prepared this Guide has taken cognizance of the following facts:

a) The issue of LV insulation co-ordination and associated reqirements are primarily recent in origin and are yet to be time tested. Considerable amount of data is required on ascertaining actual system overvoltages and the adequacy of any dielectric tests specified to verify equipment design meeting the system disturbances, and

b) LV insulation co-ordination implies the inclusion of an impulse tests even for LV equipment, covering a wide range of products manufactured under different sectors of the industry. It is not at present evident whether existing designs would be adequate to withstand the impulse ranges proposed or would involve major design changes.

0.7 However ETDC 19 had decided to prepare this Guide on the basis of international guidelines on account of the following reasons:

a) The Guide would serve as a common basis in this emerging field for various technical committees who would like to take advantage of the information contained for determining requirements for insulation co-ordination for a specific product;

b) The Guide would serve as an impetus for several experts who are engaged in collection of data pertaining to the issue and to designers to test the adequacy of their designs against acceptable reference overvoltage levels until comprehensive guidance could be worked out by individual groups; and

c) The Guide with proposed impulse levels and clearances would definitely rationalize the dimensions in a useful manner.

0.8 Therefore, the object of this Guide is to guide the relevant technical committees that have to specify creepage distance and clearances in air for low voltage equipment in such a manner that insulation coordination in the installation becomes possible, and that co-ordination between different apparatus used in the same or different situation is rationalized. It also provides the necessary data to give guidance on specifying internal insulation.

0.9 In recommending this Guide, it is stressed that it is tentative in nature. In would be periodically updated as more knowledge is gained and as comprehensive data collection would be complete. This Guide would also be supported by necessary supplementary Guides on issues where a more comprehensive treatment is necessary. Additional guidelines are being prepared on safety requirements for dimensioning of equipment, isolating distances, dielectric testing and interfaces for overvoltage categories. This Guide should also be read in conjunction with rules concerning surge protection in LV installations being prepared by Electrical Installation Sectional Committee, ETDC 20.

0.10 The degree of adoption and implementation of this Guide is the prerogative of individual technical committees preparing specification for LV equipment. In the first instance, this guide is recommended in areas where failures of LV equipment was significant. In areas where guidelines for dimensioning already exist, these could be verified in line with this Guide. For areas where technical committees are engaged in preparation of requirements for insulation co-ordination for the first time, this Guide could be used as the starting point.

0.11 It is clarified that this publication should not be construed as a design guide. However, it is believed that application of the guidelines given would lead to an economical and good design. Moreover, even though little data is available on actual system overvoltages and the adequacy of coordination of insulation to meet them in actual practice, the contents of this publication is intended to generate discussions on all relevant matters as well as streamline the collection of needed data in an organized manner. New materials developed indigenously could also be got verified in line with the available information.

0.12 It should be pointed out that this Guide adequately lays stress on the need for use of surge arresters for LV systems thereby controlling overvoltages and hence reducing the cost of equipment designed for operation downstream in the network. This is a matter of installation practice and had to be veiwed in the proper and larger perspective of current practices in the country. Detailed guidelines on this matter are outside the purview of this Guide.

0.13 In the preparation of this Guide assistance has been derived from the following publications issued by the International Electrotechnical Commission:

IEC Pub 664-1980 Insulation Co-ordination within Low-Voltage Systems including Clearances and Creepage Distances for Equipment.

IEC Pub 664A-1980 Insulation Co-ordination within Low-Voltage Systems, Including Clearances and Creepage Distance for Equipment (First supplement to Publication 664 (1980).

0.14 Since the issue of the IEC Publications given in **0.13**, several developments have taken place at the International level leading to further debate on this subject. This had led to possibilities of preparing supplementary guides and explanatory notes on the provisions on LV insulation coordination. The need for and contents of supplements are being actively debated by the High Voltage Techniques Sectional Committee, ETDC 19. Such developments as and when ready in the final form would in due course form part of this Guide.

1. SCOPE

1.1 This Guide deals with the coordination of insulation in low-voltage installations including clearances and creepage distances for equipment, bearing a rated voltage up to 1 200 V dc or up to 1 000 V ac with rated frequencies up to 30 kHz and for use up to 2 000 m above mean sea level.

1.2 The minimum clearances indicated in this Guide do not apply where ionized gases (such as flames or arcs) occur. Special requirements for such situations may be specified in the relevant standard.

1.3 This Guide does not deal explicitly with distances through solid or liquid insulation, with gases other than air or with compressed gases. However, it is recommended that any solid insulation be so dimensioned that a clearance will flashover at a value of voltage so low that no damage will be done to the solid insulation.

NOTE 1 — The rated voltages 1 000 V ac and 1 200 V dc are traditional limits for low-voltage equipment as accepted for national standardization work and only represent the formal limitation of the scope. Higher voltages may exist in circuits internal to the equipment.

NOTE 2 — The altitude of 2 000 m above mean sea level is the traditional highest altitude for low-voltage equipment covered by standards. Requirements for altitudes exceeding 2 000 m can be derived from Appendix A.

SECTION 1 DEFINITIONS

2. TERMINOLOGY

2.0 For the purposes of this Guide the following definitions shall apply.

2.1 Clearance — The shortest distance in air between two conductive parts.

NOTE — For the purpose of determining a clearance to accessible parts, the accessible surface of an insulating enclosure shall be considered conductive as if it was covered by a metal foil wherever it can be touched by a hand or a standard test finger.

2.2 Creepage Distance — The shortest distance along the surface of an insulating material between two conductive parts.

NOTE — For the purpose of determining a creepage distance to accessible parts, the accessible surface of an insulating enclosure shall be considered conductive as if it was covered by a metal foil wherever it can be touched by a hand or a test finger.

2.3 Rated Voltage — The value of voltage, assigned by the manufacturer to a component, device or equipment, to which operation and performance characteristics are referred.

NOTE — Certain types of equipment may have more than one rated voltage or may have a rated voltage range.

2.4 Rated Insulation Voltage — The voltage of a component, device or piece of equipment to which dielectric voltage tests and creepage distances are referred.

NOTE 1 — Technical committees are recommended to specify a series of rated insulation voltages for their equipment.

NOTE 2 — For equipment not having a specified rated insulation voltage. the highest value of any rated voltage shall be considered to be the rated insulation voltage.

2.5 Rated Impulse Withstand Voltage — The peak value of an impulse voltage, of prescribed form and polarity which the equipment is capable of withstanding without breakdown under specified conditions of test and to which the value of the clearances is referred.

NOTE 1 — Preferred values of rated impulse withstand voltage are those given in Table 1.

NOTE 2 — Technical committees are recommended to specify a series of rated impulse withstand voltages for their equipment.

2.6 Rated Insulation Level — The value of rated insulation voltage and rated impulse withstand voltage which characterize the insulation of equipment with regard to its ability to withstand dielectric stress.

2.7 Working Voltage — The highest rms value of the ac or dc voltage which may occur (locally) across any insulation at rated supply volts, transients being disregarded, in open circuit conditions or under normal operating conditions.

2.8 Temporary Overvoltage — The phase-to-earth, phase-to-neutral or phase-to-phase overvoltage at a given location and of relatively long duration (several seconds).

2.9 Transient Overvoltage — The transient overvoltages in the sense of this report are the following.

2.9.1 *Switching Overvoltage* — The transient overvoltage at a given location on a system due to a specific switching operation of fault.

2.9.2 *Lightning Overvoltage* — The transient overvoltage at a given location on a system due to a specific lightning discharge.

2.9.3 *Functional Overvoltage* — Deliberately imposed overvoltages necessary for the function of a device.

2.10 Impulse Withstand Voltage — The highest peak value of impulse voltages of prescribed form and polarity, which does not cause breakdown under specified conditions of test.

2.11 Power-Frequency Withstand Voltage — The rms value of a power-frequency sinusoidal voltage which does not cause breakdown under specified conditions of test.

2.12 Pollution — Any addition of foreign matter, solid, liquid or gaseous (ionized gases), that may produce a reduction of dielectric strength or surface resistivity.

2.13 Micro-environment — The ambient conditions which surround the clearance or creepage distance under consideration.

Note — The micro-environment of the creepage distance or clearance and not the environment of the equipment determines the effect on the insulation. The micro-environment might be better or worse than the environment of the equipment. It includes all factors influencing the insulation, such as climatic, electromagnetic, generation of pollution, etc.

2.14 Coordination of Insulation — The correlation of insulation characteristics of electrical equipment on the one hand with the expected overvoltages and with the characteristics of overvoltage protective devices, and on the other hand with the expected micro-environment and the pollution protective means.

Note 1 — Where the energy of the expected overvoltage is limited and where the preferred impulse withstand voltage is 1 500 V, the clearances provided may serve as simple overvoltage protective devices without causing any malfunction. The work 'malfunction' refers to discontinuity of service as well as to physical damage to the equipment itself or the surroundings. Where such use is made of a clearance, this feature must be clearly identified, so that no inadvertent design or field change could upset the coordination.

NOTE 2 — The minimum values prescribed in this Guide cannot by themselves ensure insulation coordination but make it possible. Coordination also requires the presence of gaps with a specified breakdown voltage or of overvoltage protective devices.

2.15 Isolating Distance — The clearance between open contacts of a pole of a mechanical switching device which meets the safety requirements specified for disconnectors.

2.16 Homogeneous (Uniform) Field — An electric field which has an essentially constant voltage gradient between electrodes, such as that between two spheres where the radius of each sphere is greater than the distance between them.

2.17 Inhomogeneous (Nonuniform) Field — An electric field which does not have an essentially constant voltage gradient between electrodes.

SECTION 2 INSULATION CO-ORDINATION

3. BASIC PRINCIPLES OF INSULATION COORDINATION

3.1 Insulation Co-ordination

3.1.1 Insulation co-ordination implies the selection of the electric insulation characteristics of equipment with regard to its application and in relation to its surroundings. Consideration must be given to the voltages which can appear within the system, to the location and characteristics of the overvoltage protective devices, to the continuity of service desired and to the safety of persons and property, so that the probability of undesired incidents due to voltage stresses is reduced to ensure an economically and operationally acceptable performance.

3.1.2 Insulation co-ordination requires that solid or liquid insulation materials involved have an impulse withstand voltage value in excess of the breakdown value of either the voltage limiting device or the actual clearance on which the co-ordination is based.

On the other hand the equipment itself shall not inject into the system an overvoltage in excess of the rated impulse withstand voltage.

3.1.3 Insulation co-ordination cannot be achieved only by specifying minimum values of clearances. However, it can be achieved by use of clearances having specified breakdown voltages or overvoltage protective devices having specified characteristics.

The overvoltage protective devices may be special equipment including means for the storage or dissipation of energy or simple air gaps (clearances), under defined conditions, capable of dissipating without harm the energy of the overvoltages expected at the relevant location.

3.1.4 For systems, and insulation co-ordination is based on a preferred series of impulse withstand voltage. For each location in the system the rated impulse withstand voltage of equipment shall be equal to or above the appropriate value for the particular installation category (*see* Table 1).

In order to apply this concept of insulation co-ordination, distinction should be made between two types of transient overvoltages:

a) transient originating in the system to which the equipment is connected through its terminals; and

b) transients generated within the equipment itself.

3.2 Impulse Withstand Voltages for Insulation Co-ordination — Table 1 gives the series of impulse withstand voltages related to system voltage ranges. The transient overvoltage occurring at the innerfaces in the system must remain below or be limited to the values stated. The rated impulse withstand voltage of the equipment shall be equal to or higher than the values stated.

Note — Technical committees are recommended to specify a rated impulse withstand voltage for their equipment.

3.3 Interface Requirements — In a system, the insulation levels of the various installation categories normally follow each other in descending order of magnitude of the impulse withstand voltage as the equipment is located further away from the source of energy. The transition from one installation category to the next lower category is justified by compliance with appropriate interface requirements.

Typical elements that influence the interface are:

— an overvoltage protective device;

— a transformer with isolated windings;

— a busbar system with a multiplicity of branches (capable of diverting energy of surges);

— a capacitance, for example a cable or a capacitor (capable of absorbing energy of surges); and

Note — While capacitance may be used to absorb the energy of an impulse, the effects of subsequent release of the stored energy back into the circuit must be considered.

— a resistance or similar damping device (capable of dissipating energy of surges).

3.4 Insulation Co-ordination Within a System — It is the responsibility of the technical committees dealing with installations to specify the necessary standard installation category and the interface requirements that justify the transition from one level (installation category) to the next lower level.

3.5 Insulation Co-ordination Inside a Piece of Equipment

3.5.1 For those parts in a circuit within equipment which are significantly influenced by or can themselves influence external circuit conditions, the responsible committees should suggest, if applicable, the most advantageous locations for clearances that are capable of suffering a flashover with the minimum risk of damage or disturbance. It is to be understood that all other clearances inside the same piece of equipment shall be larger (having higher impulse withstand voltage).

3.5.2 For other parts or circuits within equipment which are not significantly influenced by or cannot themselves influence external circuit conditions, the recommendations for clearances and creepage distances are not related to the installation category of the equipment but to the actual conditions for that part or circuit. Interpolation of values given in Table 2 in this case is possible.

3.6 Selection of Rated Impulse Withstand Voltage for Equipment

3.6.0 The Technical Committee responsible for the equipment considered shall indicate the installation categories according to Table 1 for which their specification applies.

3.6.1 The manufacturer shall select the rated impulse withstand voltage or range of voltage for which the equipment is designed in view of those combinations of installation category and rated voltage range for which the equipment is intended.

3.6.2 For equipment capable of creating overvoltages, for example switching devices, the magnitude of the rated implse withstand voltage implies that no overvoltage in excess of this value can be generated by the equipment itself when used in accordance with the relevant stardard and instructions of the manufacturer. Conversely, a given value of rated impulse withstand voltage implies that overvoltages of that magnitude might be generated and that, as a consequence, the equipment could be unsuitable for use in lower installation categories or it may necessitate consideration of suppression means suitable for the lower category.

NOTE — If the rated implse withstand voltage is expressed as two values of voltage, the highest value indicates the rated impulse withstand voltage and the lower value the highest overvoltage generated by the equipment itself.

TABLE 1 PREFERRED SERIES OF VALUES OF IMPULSE WITHSTAND VOLTAGES FOR RATED VOLTAGES BASED ON A CONTROLLED OVERVOLTAGE SITUATION

(*Clauses* 3.1.4, 3.2.1, 3.6.0, 3.8.1, *and* 7.1)

Voltages Phase-to-Earth Derived From Rated System Voltages up to and Including V rms and dc	Preferred Series of Impulse Withstand Voltages in Volts for Installation Category			
	I	II	III	IV
(1)	(2)	(3)	(4)	(5)
50	330	500	800	1 500
100	500	800	1 500	2 500
150	800	1 500	2 500	4 000
300	1 500	2 500	4 000	6 000
600	2 500	4 000	6 000	8 000
1 000	4 000	6 000	8 000	12 000

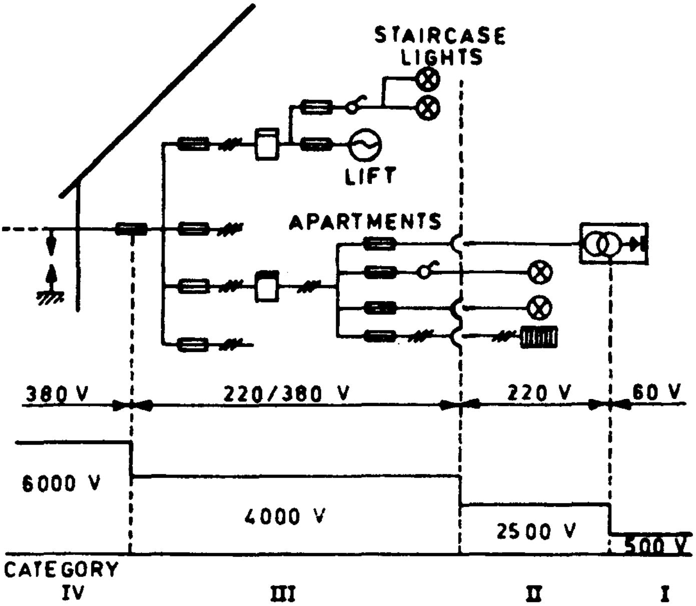
Note 1 — For the purpose of insulation co-ordination, the voltage phase-to-earth in the first column of the table is the rms value of the ac or dc voltage existing in the system under normal operating conditions.

Note 2 — The installation categories are based on protection by transient overvoltage control means, for example, surge arresters, or by other surge protectors, such as spark gaps (clearances) designed for this purpose or by metal oxide varistors, etc, unless the nature of the installation is such that the impulse withstand voltage of the selected category is not exceeded (*see* Fig. 1).

Note 3 — For systems where no surge suppressor is installad, the situation can be described as 'uncontrolled'. However, overvoltages will still be ultimately limited by sparkover of air clearance (self-restoring) or by puncture of solid insulation (permanent failure), whichever is the lowest. This ultimate voltage (typically between 5 kV and 25 kV) is determined by the design or actual construction of the hardware and is subject to unpredicable factors. Clearly, the indeterminate levels of voltage as well as the permanent puncture risks, make the uncontrolled approach undesirable.

Note 4 — For unearthed (ungrounded) systems or systems with one phase earthed (grounded phase), the phase-to-earth voltage is to be considered as the phase-to-phase voltage.

3.8 Preferred Series of Values of Impulse Withstand Voltages for Rated Voltages Based on an Overvoltage Controlled Situation — Table 1 is a proposal for future system design which includes interface requirements to establish limited impulse voltage conditions at specific locations on the system. It must be recognized that overvoltage controlled systems do not generally exist at this time. However, it must also be recognized that this type of system must exist before true insulation co-ordination can be achieved. In the meantime, individual technical committees can achieve more efficient design standards by considering the use of transient overvoltage control means to achieve the voltage levels proposed in Table 1 (*see also* Appendix B).



Installation Category IV	*Installation Category III*	*Installation Category II*	*Installation Category I*
Primary supply level. Overhead lines and cable systems including distribution bus and its associated overcurrent protection equipment.	Fixed installation following installation category IV.	Appliances, portable equipment etc, following installation category III.	Special equipment or parts of equipment following installation category II, telecommunication electronic, etc.

NOTE — A lower installation category may follow any higher installation category when appropriate transient overvoltage control means (interfaces) are provided.

FIG. 1 EXAMPLE FOR INSTALLATION CATEGORIES I TO IV AND INSTALLATION CO-ORDINATION ACCORDING TO TABLE 1

SECTION 3 CLEARANCES IN AIR

4. INFLUENCING FACTORS

4.0 The requirements of clearances in air are determined by the micro-environment in which the (clearance) under consideration is situated (also *see* Appendix C).

4.1 Fundamental Factors Influencing Clearance — The fundamental factors influencing clearance are (*see also* **5**):

a) transient overvoltages,
b) electric field condition (shape of the electrodes),
c) pollution, and
d) altitude.

4.2 Other Factors which may Influence a Clearance — The other factors influencing clearance are (*see also* **6**):

a) protection against electric shock,
b) mechanical aspects,
c) isolating distance,
d) consequences of an insulation fault in a circuit, and
e) continuity of service.

5. DESCRIPTION OF THE FUNDAMENTAL FACTORS INFLUENCING CLEARANCE

5.0 The minimum clearances are obtained by application of this clause. However, the other conditions given in **4.2** may require increased distance which are not directly dimensionable but are the responsibility of the individual technical committees and should take into consideration **6.**

5.1 Transient Overvoltages—For the purpose of withstanding transient overvoltages, the impulse withstand voltage of a clearance in air has been derived for homogeneous (Case B) and inhomogeneous (Case A) fields under normal conditions of temperature and relative humidity and for a barometric pressure of 80 kPa (corresponding to an altitude of about 2 000 m above mean sea level). Daily variations in barometric pressure have been disregarded.

NOTE — Information on this can be found in Appendix A.

5.2 Electric Field Conditions — The shape and arrangement of the conductive parts (electrodes) between which the clearance exists influence the homogeneity of the field and consequently the distance needed to withstand a given voltage (*see* Appendix A and Table 2).

5.2.1 *Case A of Table 2* — Values of clearances equal to or larger than those in Table 2 under Case A can be used irrespective of electrode configuration and without verification by electric impulse test. Case A clearance values are accepted as having under all conditions the ability to withstand the rated impulse withstand voltage.

5.2.2 *Case B of Table 2* — Values of clearances in Table 2 under Case B represent ideal conditions that may be approached when the electrode configuration is designed to minimize local electric stresses.

Clearance values which are between Case A and Case B values require verification by test.

NOTE — For small values of clearances, the presence of pollution may destroy the uniformity of the field, making the use of Case B impossible, or at least unreliable.

For rated impulse withstand voltages higher than 6 000 V, the clearances are large enough for pollution not to influence significantly the uniformity of the electric field.

5.3 Pollution

5.3.0 Means may be provided to reduce pollution at the clearance under consideration by effective use of enclosures, encapsulation or hermetic sealing. It should be recognized that such means to reduce pollution may not be effective when the equipment is subject to condensation or if, in normal operation, it generates pollutants itself.

The effects of pollution in the micro-environment need only be taken into account when the position and orientation of the clearance are such that deposition of dust, dirt, water, etc, is likely to occur in a manner to reduce the clearances.

Small clearances can be bridged completely by solid particles, dust and water, and therefore minimum clearances are specified where pollution may be present in the micro-environment.

NOTE — The conductivity under polluted conditions is mainly caused by water, soot, metal dust, carbon dust or similar components. Conductive pollution by ionized gases and metallic deposition is restricted to specific instances, for example in switchgear or controlgear which are not covered by this guide.

Where ionized gases are present the necessary clearances cannot be specified. Ionized gases often occur coincidental to switching surges. When appropriate manufactures of switching equipment will indicate the safety zone beyond which no ionized gases will appear during normal operation.

5.3.1 *Degrees of Pollution in the Micro-environment* — For the purpose of evaluating clearances, the following four degrees of pollution in the micro-environment are established:

a) *Pollution Degree 1* — No pollution or only dry, non-conductive pollution occurs. The pollution has no influence. The clearance has to be determined only according to the voltage as described in **5.1** and **5.2**.

b) *Pollution Degree 2* — Normally, only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation must be expected. The clearance has to be determined only according to the voltage as described in **5.1** and **5.2**. However, the minimum clearance is 0·2 mm.

c) *Pollution Degree 3* — Conductive pollution occurs, or dry, non-conductive pollution occurs which become conductive due to condensation which is expected. The clearance has to be determined only according to the voltage as described in **5.1** and **5.2**. However, the minimum clearance is 0·8 mm.

d) *Pollution Degree 4*—The pollution generates persistent conductivity caused, for instance, by conductive dust or by rain or snow. The clearance has to be determined only according to the voltage as described in **5.1** and **5.2**. However, the minimum clearance is 1·6 mm.

NOTE — The minimum clearances given for pollution degrees 2, 3 and 4 are based on experience rather than on fundamental data.

5.4 Altitude

5.4.0 Breakdown voltage of a clearance in air, for a homogeneous field (withstand voltage Case B in Table 6), is according to Paschen's Law, proportional to the product of the distance between electrodes and the atmospheric pressure. Therefore, experimental data recorded at approximately sea level are calculated, according to the difference in atmospheric pressure between 2 000 m and sea level. For the purpose of this Guide, the similar calculation is made for inhomogeneous fields.

As the given millimetre values in Table 2 are valid for an altitude of 2 000 m above sea level, clearance for other altitudes must be multiplied by the multiple factor for distance. This correction factor corresponds to Paschen's Law. The relevant table is shown in Appendix A.

TABLE 2 MINIMUM CLEARANCES FOR INSULATION CO-ORDINATION

(*Clauses* 3.5.2, 5.2, 5.4.0 *and* 8.1)

Rated Impulse Withstand Voltage Peak kV	Minimum Clearances in Air in Millimetres Up to 2 000 m Above Sea Level							
	Case A (Inhomogeneous Field Conditions) (*see* **2.17**) No Dielectric Test Required				Case B (Homogeneous Field, Ideal Conditions) (*see* **2.16**) Dielectric Test Required*			
	Pollution degree				Pollution degree			
	1	2	3	4	1	2	3	4
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0·33†	0·01	↑	↑	↑	0·01	↑	↑	↑
0·40	0·02	│	│	│	0·02	│	│	│
0·50†	0·04	│	│	│	0·04	│	│	│
0·60	0·06	0·2	│	│	0·06	0·2	│	│
0·80†	0·10	│	0·8	│	0·1	│	0·8	│
1·0	0·15	↓	│	1·6	0·15	│	│	1·6
1·2	0·25	0·25	│	│	0·2	↓	│	│
1·5†	0·5	0·5	↓	│	0·3	0·3	│	│
2·0	1·0	1·0	1·0	│	0·45	0·45	│	│
2·5†	1·5	1·5	1·5	↓	0·6	0·6	│	│
3·0	2	2	2	2	0·8	0·8	↓	│
4·0†	3	3	3	3	1·2	1·2	1·2	│
5·0	4	4	4	4	1·5	1·5	1·5	↓
6·0†	5·5	5·5	5·5	5·5	2	2	2	2
8·0†	8	8	8	8	3	3	3	3
10	11	11	11	11	3·5	3·5	3·5	3·5
12†	14	14	14	14	4·5	4·5	4·5	4·5
15	18	18	18	18	5·5	5·5	5·5	5·5
20	25	25	25	25	8	8	8	8
25	33	33	33	33	10	10	10	10
30	40	40	40	40	12·5	12·5	12·5	12·5
40	60	60	60	60	17	17	17	17
50	75	75	75	75	22	22	22	22
60	90	90	90	90	27	27	27	27
80	130	130	130	130	35	35	35	35
100	170	170	170	170	45	45	45	45

*Verification by a dielectric test is required if the clearance is less than the value specified for Case A.

†Preferred values used in Table 1.

6. DESCRIPTION OF THE OTHER FACTORS WHICH MAY INFLUENCE A CLEARANCE

6.0 The clearances specified here must be retained throughout the useful life of the equipment taking into account the othet factors. In some cases, increase of the clearance may be necessary to achieve this result. However, a mere increase of clearance may not in itself ensure this result, for example, due to mechanical aspects.

Technical committees should establish clerances for products within their scope taking into account relevant influencing factors.

6.1 Additional Insulation and Measures to Provide Protection Against Electric Shock— Attention is drawn to IS : 9409-1980* wherein it is intended to give guidance to technical committees on the classification of low-voltage electrical and electronic equipment intended for connection to an external supply with regard to protection against electric shock in the event of an insulation failure.

For supplementary insulation and for reinforced insulation the technical committee concerned shall state the rules governing clearances for the equipment in its scope of work.

6.2 Mechanical Aspects — The extent to which the manufacturing process can control the mechanical tolerances decides the limit to which practical clearances can approach the theoretical minimum clearances. It is possible to approach minimum clearances when the equipment is manufactured in a factory under controlled conditions and finished to a point where additional assembly other than the connections to terminals prior to placing the equipment in service, is not necessary. Replacement of components normally effected in service shops or in normal use (e. g. fuses) are considered to be part of controlled conditions. Routine maintenance schedules for testing or examining insulaion are expected.

Increased clearances are required when equipment is field-mounted and field-connected because the method of mounting and the wiring method at the terminals have to be considered.

6.3 Isolating Distance — Isolating distances are determined in the same manner as clearances.

The ratio of the impulse withstand voltage for the isolating distance to the rated impulse withstand voltage is under consideration.

6.4 Consequences of an Insulation Fault in a Circuit — Under consideration.

6.5 Continuity of Service — Under consideration.

NOTE — Insulating material may undergo dimensional changes (deformation) after being incorporated in equipment. This includes changes due to loss of constituents due to evaporation as well as flow due to thermal or mechanical stress, absorption of water (swelling) or chemical changes.

Particular attention should be given to gaskets that may be unduly compressed or even lost.

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*Classification of electrical and electronic equipment with regard to protection against electric shock.

Special attention should be given to the possibility of elastic deformations, as they may not be present at the time of inspection, but only under certain conditions of service.

Mechanical displacement of parts, whether operational due to the motion of movable parts, or more permanent such as the displacement of terminals due to the attachment of wires, should be considered and liberally compensated for.

7. DIELECTRIC TESTS

7.0 All dielectric tests stated in this guide are type tests. Technical committees shall specify which tests are applicable.

When using the minimum clearance values in accordance with Case A values, no withstand voltage tests are required. Withstand voltage tests are required only when using values less than Case A values and greater than Case B values. There should be no disruptive discharge during the tests.

7.1 Preparation for Dielectric Test — When clearances are verified by dielectric tests, it is up to the manufacturer to ensure that irrespective of manufacturing tolerances the products will comply with the test requirement. An increase of test voltage shall be considered if the test is performed at an altitude below 2 000 m (*see* Appendix A).

Example 1 :

An equipment with a rated voltage of 230 V phase-to-earth for use up to 2 000 m above sea level and an installation category III is required to withstand an impulse voltage of 4 000 V according to Table 1.

This equipment is to be tested at a site located 500 m above sea level. What is the required impulse withstand voltage at 500 m.

The Case B clearance at 2 000 m and 4 000 V impulse withstand voltage according to Table 6 is 1·2 mm (actual value is 4 090 V).

The multiplying factor for distance, at 500 m according to Appendix A is 0·84.

Therefore, the equivalent increase in distance corresponding to 500 m is:

$$1{\cdot}2 \text{ mm} \times \frac{1{\cdot}00}{0{\cdot}84} = 1{\cdot}43 \text{ mm}$$

The corresponding impulse withstand voltage for 1·43 mm clearance from Table 3 (by interpolation from Case B) is 4 750 V. This value can also be read from Fig. 4, curve 1 for 1·43 mm.

Example 2 :

What is the required impulse withstand voltage for the equipment of Example 1 when tested at sea level ?

The multiplying factor for distance at sea level is 0·79.

Therefore, the equivalent increase in distance corresponding to sea level is:

$$1{\cdot}2 \text{ mm} \times \frac{1{\cdot}00}{0{\cdot}79} = 1{\cdot}52 \text{ mm}$$

The impulse withstand voltage is 5 000 V (by interpolation from Table 3) or from Fig. 4, curve 1 for 1·52 mm.

7.2 General Requirements for Test — In principle, the test for impulse withstand voltage shall be performed by an impulse test according to **7.4**.

When the conducting parts to which the test voltage is applied are permanently connected to parts or components that may influence the magnitude or duration of the impulse, for example, surge arresters or capacitors, only the impulse test with the specified energy according to **7.4** is applicable.

If a sustained voltage of the magnitude of the test voltage cannot harm any of the components in parallel with the clearance under test, a dc test may be used instead of the impulse test.

If the above conditions are satisfied and solid insulation is not unduly stressed, an ac test with a peak value corresponding to the required test voltage may be used.

7.3 Results to be Obtained — When a peak voltage according to the desired insulation level is applied, no flash-over or breakdown shall occur. Corona effects which do not result in breakdown are disregarded.

7.4 Impulse Test Procedure — Under consideration.

SECTION 4 CREEPAGE DISTANCES

8. CREEPAGE DISTANCES

8.0 General — The recommendations for creepage distances are based on a considerable amount of empirical data and on a basic review of the physical mechanisms behind various influencing factors, rather than on exact measurements of known physical phenomena.

8.0.1 A possible deterioration over the useful life of a creepage distance or the total failure of insulation properties depends on many factors just as the magnitude of the surface leakage current over a creepage distance does not present any simple physical dependency on distance and voltage. A number of aspects have still to be studied.

8.0.2 For equipment operating within certain voltage ranges and under certain operating conditions a vast amount of practical experience exists, forming a useful guide for design purposes. Such empirical values form a part of this Guide bearing in mind that certain existing standards require distances significantly greater than would be necessary from a technical point of view and that good experience with equipment designed in accordance with such standards is no proof that larger distances are really necessary. The values for printed boards are based on a statistical evaluation of a series of tests. Different circumstances may require greater or permit smaller creepage distances than those given in Table 3. This decision shall be made by the individual technical committees.

8.0.3 In view of the necessity that as much protection against deterioration of the properties of insulating material as possible is to be achieved, the values given in Table 3 present creepage distances where the influencing factors, pollution degree and the properties of insulating material are taken into account. These distances represent conditions of continuous stress. It should be pointed out however that the exclusion or diversion of contamination by design measures and the proper selection of a suitable type of insulating material have a greater influence on the performance than the values of the creepage distances contained in Table 3.

8.0.4 Clearance and creepage distances serve different purposes in the insulation co-ordination, and therefore it may happen that the minimum creepage distance established on the basis of the following will be smaller than the minimum clearance determined in accordance with Section 3. In that case, the clearance becomes the deciding design basis.

8.1 Influencing Factors — Creepage distances are determined by the micro-environment in which the distance under consideration is situated.

NOTE — This means that in the same piece of equipment widely different creepage distances may be permitted.

8.2 Fundamental Factors Influencing Creepage Distances

a) Rated insulation voltage or working voltage (*see* **9.2**),

b) Pollution (*see* **9.3**),

  i) Moisture,

  ii) Orientation and location of a creepage distance (*see* **9.5**),

    - iii) Shape of insulating surface (*see* **9.6**),
    - iv) Electrostatic precipitation (*see* **9.7**)
- c) Insulating materials (*see* **9.4**),
- d) Relationship to clearance (*see* **9.1**),
- e) Time under voltage stress (*see* **9.8**), and
- f) Other factors which may influence creepage distance:
    - i) *Surface leakage current* (*see* **9.9**) — It may be necessary to reduce the surface leakage current in order:
        - — to prevent damage to insulating material,
        - — to prevent perception current (electric shock), and
        - — to maintain proper functioning of the equipment (crosstalk).
    - ii) Consequences of an insulation fault in a circuit, including continuity of service (*see* **9.10**):
    - iii) Constructional aspects (*see* **9.11**), and
    - iv) Properties of electrode material (*see* **9.12**).

9. SPECIFICATION OF THE INFLUENCING FACTORS

9.1 Relationship to Clearance — A creepage distance cannot be less than the associated clearance, so that the shortest creepage distance possible is equal to the clearance. However, there is no physical relation between the minimum clearance in air and the minimum acceptable creepage distance, except for this dimensional limitation.

With respect to flashover, creepage distances less than the clearances required by Case A of Table 2 may only be used under conditions of pollution degree 1 in which situation the associated clearance test by impulse withstand voltage or equivalent rms voltage test for the creepage distances is sufficient.

9.2 Voltage — The basis for the determination of a creepage distance is the rms or dc value of the voltage existing between electrodes and across the creepage distance for an extended period of time. Transient overvoltages are neglected on the basis of the fact that they will normally not influence the tracking phenomenon. However, temporary and functional overvoltages may have to be considered, depending upon duration and frequency of occurence. Voltages which result in partial discharges also require additional consideration in the selection of insulating material.

9.3 Pollution (*see* **5.3.1**) — The degrees of pollution which were specified for clearances shall apply also to creepage distances.

9.3.1 *Condensation* — The condensation of water shall always be considered a possibility, except in the case of pollution degree 1. Condensation will occur in the case of pollution degrees 2, 3 and 4 as a result of the following condition:

a) *Where the temperature of insulation surface falls below the dew-point of the surrounding air.*

NOTE 1 — The statement in (a) implies that the risk of condensation is negligible within a certain type of equipment (for example, a radio receiver) used in an enclosed space, such as a weakened housing. Cooling of the house will, when the dew-point is attained, result in condensation on the walls of the house, but not to condensation in the equipment located inside the house.

When heating the house (from the outside or from the inside), parts having a high thermal capacity (walls, structure, etc) will always lag with regard to equipment having a relatively low thermal capacity. Hence there is a negligible risk resulting from condensation within the equipment and pollution degree 1 conditions normally exist. A similar consideration is valid for small components located within a larger enclosure.

On the other hand, an enclosure exposed to a low temperature ambient, but constructed in a manner that allows the exchange of air with a higher ambient temperature, may be subject to continuous condensation.

Examples are boxes built into external walls, but with openings to an inside room or conduits passing through a low-temperature area. Unless properly drained, condensate may collect in such enclosures.

Enclosures subject to variation of temperature (for example, between day and night) are particularly prone to cumulative condensation because the variations promote the air exchange (breathing).

NOTE 2 — In the case of creepage distances in the vicinity of components dissipating a small quantity of heat, the micro-environment may differ considerably from the surrounding environment of the equipment as far as condensation and tracking are concerned. Close to the source of heat, drying-out is achieved quickly, which results in low conductivity of the surface so that tracking will not occur. However, for certain designs, the water vapour may recondense on cold sports located elsewhere and may thus increase the risk of tracking at such places.

b) *Where the insulation surface is contaminated with*:

a) hygroscopic dust, or

b) salt and the relative humidity is above a particular value.

NOTE — For example, in the presence of salt, condensation may take place where the surrounding air has a relative humidity as low as 40 percent.

Unless suitable precautions are taken, condensation may occur in any enclosure but condensation may be reduced or eliminated by one or more of the following means:

— the use of a dried and hermetically sealed enclosure; it should be noted that 'hermetically sealed' implies an absolutely airtight enclosure so that an exchange of humid air, caused by a normal change in air pressure, is impossible;

- the use of an enclosure with ventilation;
- heating of the equipment either by continuous energization or by the use of supplementary heaters;
- maintaining the surrounding air at constant temperature and suitably low relative humidity; and
- encapsulation (for example, potting).

9.3.2 *Conductive Dust* — In certain locations, conductive deposits may be present. Such deposits can be avoided by means of suitable enclosures around the creepage distance in question, but attention must be paid to the fact that within that enclosure conductive deposits may be produced, for example, those originating from carbon brushes, in which case this enclosure will not ensure protection and may even aggravate the problem.

Conductive dust can lead to very high values of surface leakage currents, and can lead to failure by a flashover, but it seldom leads to progressive tracking.

9.4 Insulating Materials

9.4.1 *Characteristics of Insulating Materials* — Insulating materials can be roughly characterized according to the damage they may suffer from concentrated release of energy as a result of the action of electric arcs (mini-arcs) when a surface leakage current is interrupted, that is, due to drying of the contaminated surface. The following behaviour of insulating materials in the presence of mini-arcs may occur:

a) no decomposition of the insulating materials,

b) decomposition of material into volatile components (erosion), and

c) decomposition of material resulting in carbon residues (tracking).

NOTE 1 — The test in accordance with IS : 2824-1975* makes it possible to visually determine whether the insulating material under test will:

- remain unaffected by the test conditions, or
- have a tendency to erode, or
- have a tendency to form tracks.

But in practice, erosion and tracking can be more or less intermixed, depending on the kind of insulating material, contamination and current (ac or dc).

NOTE 2 — Tracking or erosion cannot occur unless the surface leakage current exceeds a limiting value related to the minimum energy necessary to create the chemical decomposition required for tracking in a localized drying out situation or equivalent changes in the surface conductivity. These situations arise when the electrodes of a contaminated creepage distance are energized or when the creepage distance between energized electrodes becomes contaminated. The magnitude of the surface leakage current depends upon the conductive of the contamination of the surface and on the configuration of the relevant parts. The progression of tracking or of erosion increases with the number of localized dry-out incidents.

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*Methods for determining comparative tracking index of solid insulating materials under moist conditions (*first revision*).

A method of classification for insulating materials according to groups (a), (b) and (c). does not exist. The behaviour of the inuslating material under various contaminants and voltages is extremely complex. Under these various conditions many material will fall into two or even all three of the groups (a), (b) and (c).

A direct correlation of groups (a), (b) and (c) with the material groups of 9.4.2 is not practical. However, it has been found by experience and tests that insulating materials having a higher relative performance also have approximately the same relative ranking according to the Comparative Tracking Index (CTI). Therefore, this Guide uses the CTI values to establish a selection of insulation materials for dimensioning in Table 3.

9.4.2 *Comparative Tracking Index (CTI)* — The test for Comparative Tracking Index in accordance with IS : 2824-1975*, is designed to compare the performance of various insulating materials under test conditions, namely drops of an aqueous contaminent falling on a horizontal surface leading to electrolytic conduction. Basically, it gives a qualitative comparison, but in the case of insulating materials having a tendency to form tracks it may also give a quantitative comparison, the Comparative Tracking Index.

For the purpose of this Guide materials are separated into four groups according to their CTI values, as follows:

Material Group I	$600 \leqslant \mathrm{CTI}$
Material Group II	$400 \leqslant \mathrm{CTI} < 600$
Material Group IIIa	$175 \leqslant \mathrm{CTI} < 400$
Material Group IIIb	$100 \leqslant \mathrm{CTI} < 175$

The above CTI values refer to values obtained in accordance with IS : 2824-1975*, on samples specifically made for the purpose and tested with Appendix A.

NOTE — For inorganic insulating materials, for example glass or ceramics, which do not track, creepage distances need not be greater than their associated clearance for the purpose of insulation co-ordination.

9.5 Orientation and Location of a Creepage Distance — The orientation and location of a creepage distance is significant in the following ways:

a) The tendency to collect dust which is deposited by gravity centrifugal force or by draughts of air as a result of natural or induced circulation,

b) The flow pattern or drops of water over the surface in between electrodes or form one electrode to another, and

c) The location of a creepage distance with respect to a heat source causing accelerated uniform drying of the insulating surface.

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*Methods for determining comparative tracking index of solid insulating materials under moist conditions (*first revision*).

The pollution is influenced by the position in which the equipment or component is installed in a room, frame, or enclosure. All intended positions should be considered when evaluating the pollution for the creepage distance. Particular attention should be given to equipment or components that may change their position while in use, for example, portable equipment or moving parts of mechanically operated switches.

NOTE 1 — The manufacturer should indicate the intended orientation of the equipment or component, if a particular orientation is required or excluded.

NOTE 2 — It should be recognized that equipment may be stored in one orientation but be used in another and this may influence the collection of dust.

9.6 Shape of Insulating Surface — Creepage distances may preferably include transverse ridges and grooves that break the continuity of the leakage path caused by conductive surface layers. Likewise, ridges and grooves may be used to divert the flow of drops of water to areas not under electrical stress. Joint grooves or cracks running parallel between the conductive parts (the electrodes) should be avoided as they may collect pollution or retain water by capillary action.

Examples of the evaluation of the length of a creepage path are given in the examples 1 to 11 in clause **11.**

9.7 Electrostatic Precipitation — In the presence of electrostatic fields, contaminating non-conductive dust particles can be deposited on insulating surfaces where otherwise dust may not accumulate to the same degree.

The adhesion and accumulation of precipitated dust particles result from the presence of high unidirectional electric fields and are independent of material orientation.

9.8 Time Under Voltage Stress — The time under voltage stress influences the number of drying out incidents capable of causing mini arcs of an energy high enough to entail tracking. The number of drying out incidents is considered to be sufficiently large to cause tracking:

— in equipment intended for continuous use and not generating in its interior sufficient heat for drying out;

— in any equipment of the input side of any switch and between the line and load (input and output) terminals of any switch supplied from the mains; and

— in any equipment subject to condensation for longer periods, and being frequently switched on and off.

The creepage distances shown in Table 3 have been determined for insulation intended to be under voltage stress for a long time (or continuously). Technical committees concerned with insulation for equipment which is under voltage stress for only a short time may consider using shorter creepage distances than those recommended in Table 3.

NOTE — For pollution degree 2, a material of lower CTI may be used as suggested in Note 1 to Table 3.

Alternatively, except for pollution degree 4, the creepage distance corresponding to one voltage step lower may be used for insulation stressed for a total of 15 000 h or less. Similarly, for insulation stressed 1 500 h or less, the creepage distance corresponding to two voltage steps lower may be used. These degrees of relaxation from the conditions of continuous stress are provisional and under consideration. Therefore, interested technical committees are invited to give their experience.

The same consideration may be given to insulation which is only intermittently stressed within equipment which is itself under voltage stress for a long time. Consideration of even smaller distances may be given in the cases of insulation of floating (not energized or not capable of being earthed) parts.

9.9 Considerations to Reduce Leakage Current — The consequence of a creepage distance with conductive contamination, whether it is inherently conductive or conductive because of humidity, is that it permits a leakage current over the insulating surface. The magnitude of this leakage current is a function of the voltage and impedance of the source, the conductivity of the pollution and both the length and width of creepage distance.

9.9.1 *Protection Against Electric Shock* — Any leakage current to an accessible part presents a risk of electric shock if leakage current can exceed the perception level when the accessible part is touched by a human body in contact with earth. The leakage current to be considered is the sum of the capacitative, conductive and surface leakage current but only the latter is dealt with here.

When evaluating the risk of electric shock by a surface leakage current from an accessible part which is not earthed directly or indirectly, it should be remembered that such a current can only flow when the accessible part is earthed, for example, by touching. Therefore, a wet surface will not dry out due to leakage current, but for the same reason no tracking can occur.

Consideration should be given to joints, cracks, and crevices that may retain water by capillary action and also form part of the leakage path.

NOTE — With regard to safety (perception current), the possibility of such joints, cracks and crevices becoming conductive should be considered.

Similar considerations relate to the collection of conductive dust, for example from the commutator of motors or from other switching devices.

9.9.2 *Protection Against Malfunctioning* — Considerations very similar to those relating to electric shock are valid in connection with leakage current crosstalk or similar malfunction. Because of its irregular and unpredictable nature, surface leakage currents should be considered when evaluating the influence of one circuit on the operation of another circuit, such as in communications equipment and in sensitive control circuits. However, it is not possible to indicate specific values of leakage current since the highest tolerable value depends upon circumstances. In general, proper attention to the character and location of the circuits is of far greater significance than the dimensioning of the creepage distances involved. Sensitive circuitry may require the exclusion of contamination and moisture [*see also* **9.3.1**(b)].

9.10 Consequences of an Insulation Fault in a Circuit — Tracking of the insulation is likely to result in permanent failure. The possible consequence of this, whether it is the starting of a fire, the interruption of an essential supply or any other undesirable circumstance, must be considered by the technical committees which may take steps to give greater degree of protection. These steps may include for example increased creepage distance, better materials, encapsulation, etc.

On the other hand, circumstances may justify a reduction of the creepage distances.

The following should be considered:

a) A leakage current leading to tracking in a circuit may cause a short circuit and consequential operation of the overcurrent protective device if the circuit impedance is low enough. The damage depends upon the resulting current and the operating characteristics of the overcurrent protective device.

b) A fire may be caused by a leakage current leading to tracking in a circuit where impedance is too high to cause the overcurrent protective device to operate.

c) In high-power circuits, the power of the fault arc can be appreciable, even though the operation of the overcurrent protective device may be very fast or even current limiting, the energy released can be appreciable and capable of causing mechanical damage (pressure) and fire.

d) In some cases the impedance of the circuit is so high or the micro environment is so favourable that tracking is unlikely to occur. Provided that a short circuit in such a case will not constitute a fire hazard, electric shock or malfunction, the creepage distance need not exceed the clearance.

TABLE 3 MINIMUM CREEPAGE DISTANCES IN MILLIMETRES FOR A MICRO-ENVIRONMENT DEPENDENT ON VOLTAGE, POLLUTION DEGREE, INSULATING MATERIAL AND THEIR USE ON PRINTED WIRING MATERIAL OR IN EQUIPMENT VOLTAGE VALUES SELECTED IN ACCORDANCE WITH THE R 10-SERIES

(*Clauses* 8.0, 9.4.1, 9.8 *and* 10.0)

VOLTAGE V ac rms or dc	PRINTED WIRING MATERIAL			CREEPAGE DISTANCES IN MILLIMETRES FOR EQUIPMENT SUBJECT TO LONG-TERM STRESS											
	Pollution Degree			Pollution Degree 2				Pollution Degree 3				Pollution Degree 4			
	1	2	1	Material group				Material group				Material group			
	See Note 2	*See* Note 3	*See* Note 2	I (*See* Note 1)	II	IIIa	IIIb	I	II	IIIa	IIIb	I	II	IIIa	IIIb
10	0·025	0·04	0·08	0·4	0·4	0·4		1	1	1		1·6	1·6	1·6	See Note 4
12·5	0·025	0·04	0·09	0·42	0·42	0·42		1·05	1.05	1·05		1·6	1·6	1·6	
16	0·025	0·04	0·1	0·45	0·45	0·45		1·1	1.1	1·1		1·6	1·6	1-6	
20	0·025	0·04	0·11	0·48	0·48	0·48		1·2	1.2	1·2		1·6	1·6	1·6	
25	0·025	0·04	0·125	0·5	0·5	0·5		1·25	1.25	1·25		1·7	1·7	1·7	
32	0·025	0·04	0·14	0·53	0·53	0·53		1·3	1.3	1·3		1·8	1·8	1·8	
40	0·025	0·04	0·16	0·56	0·8	1·1		1·4	1.6	1·8		1·9	2·4	3	
50	0·025	0·04	0·18	0·6	0·85	1·2		1·5	1·7	1·9		2	2·5	3·2	
63	0·04	0·063	0·2	0·63	0·9	1·25		1·6	1·8	2		2·1	2·6	3·4	
80	0·063	0·1	0·22	0·67	0·95	1·3		1·7	1·9	2·1		2·2	2·8	3·6	
100	0·1	0·16	0·25	0·71	1	1·4		1·8	2	2·2		2·4	3·0	3·8	
125	0·16	0·25	0·28	0·75	1·05	1·5		1·9	2·1	2·4		2·5	3·2	4	
160	0·25	0·4	0·32	0·8	1·1	1·6		2	2·2	2·5		3·2	4	5	
200	0·4	0·63	0·42	1	1·4	2		2·5	2·8	3·2		4	5	6·3	
250	0·56	1	0·56	1·25	1·8	2·5		3·2	3·6	4		5	6·3	8	
320	0·75	1·6	0·75	1·6	2·2	3·2		4	4·5	5		6·3	8	10	
400	1	2	1	2	2·8	4		5	5·6	6·3		8	10	12·5	
500	1·3	2·5	1·3	2·5	3·6	5		6·3	7·1	8·0		10	12·5	16	
630	1·8	3·2	1·8	3·2	4·5	6·3		8	9	10		12·5	16	20	
800	2·4	4	2·4	4	5·6	8		10	11	12·5	See Note 4	16	20	25	
1 000	3·2	5	3·2	5	7·1	10		12·5	14	16		20	25	32	
1 250			4·2	6·3	9	12·5		16	18	20		25	32	40	
1 600			5·6	8	11	16		20	22	25		32	40	50	
2 000			7·5	10	14	20		25	28	32		40	50	63	
2 500			10	12·5	18	25		32	36	40		50	63	80	
3 200			12·5	16	22	32		40	45	50		63	80	100	
4 000			16	20	28	40		50	56	63		80	100	125	
5 000			20	25	36	50		63	71	80		100	125	160	
6 300			25	32	45	63		80	90	100		125	160	200	
8 000			32	40	56	80		100	110	125		160	200	250	
10 000			40	50	71	100		125	140	160		200	250	320	

NOTE 1 — Material group I or Material groups II, IIIa, IIIb ~~where likelihood to track~~ is reduced due to conditions of 9.8.

NOTE 2 — Material groups I, II, IIIa, IIIb.

NOTE 3 — Material groups I, II, IIIa.

NOTE 4 — Values of creepage distances in this area have not been established. Material group IIIb is in general not recommended for application in pollution degree 3 above 630 V and in pollution degree 4. Available data indicate that such application may require spacings very much greater than those in Material group IIIa. But on the decision of a Technical Committee Material group IIIb may be used in this area if it can be shown by experience or by design of a particular equipment or by test to be satisfactory.

NOTE 5 — It is appreciated that tracking or erosion will not occur on insulation subjected to working voltages of 32 V and below. However, the possibility of electrolytic corrosion has to be considered and for this reason minimum creepages have been specified.

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9.11 Constructional Aspects — Special attention should be given to terminals, where the effective creepage distance can be shortened by the conductors attached to the terminals, for example by touching ridges separating two terminals or by hygroscopic action of the conductor insulation. Minimum creepage distances associated with terminals may be solely governed by constructional considerations as specified by the relevant technical committees (*see also* **6.2**).

9.12 Properties of Electrode Material — For small values of creepage distances, it may be necessary to consider the fact that some electrode materials have a tendency to migrate under the influence of a leakage current or to form dendrites (whiskers) which may reduce both clearance and creepage distances. Other materials, or particular alloys may exhibit dimensional growth due to recrystallization, usually very slowly in the order of years. Some electrode materials tend to dissolve in electrolytic pollutants, thereby increasing the conductivity and thus increasing the probability of tracking or flashover.

9.13 Other Conditions — Other conditions may require the consideration of supplementary factors which are not directly dimensionable and are the responsibility of the individual technical committees. Considerations of ribs and grooves are given in **9.6**.

10. DIMENSIONING OF CREEPAGE DISTANCES

10.0 The values of creepage distances given in Table 3 are based upon existing empirical data and are suitable for a majority of applications but exclude certain applications for which other values of creepage distances are appropriate.

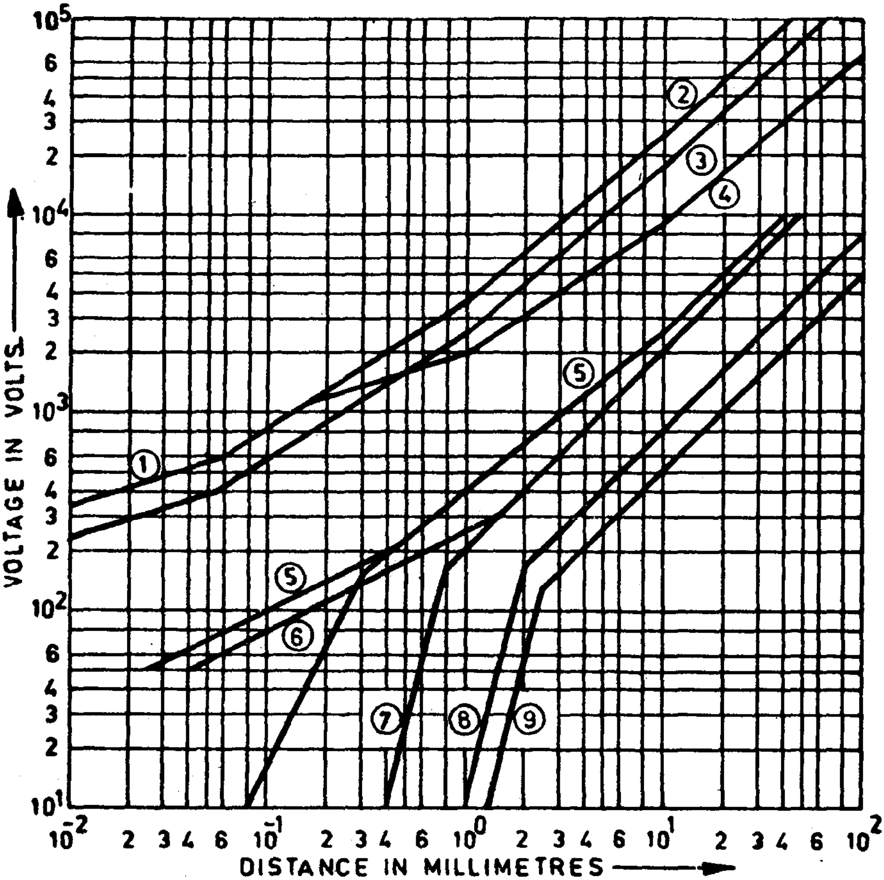
Technical committees may have experiences which are valid under certain conditions specific to their products. In these cases other creepage distances either smaller or larger than those given in Table 3 may be selected taking the influencing factors of **9.5** to **9.12** into account.

Where the working voltage is used for dimensioning, it may be appropriate to interpolate values for intermediate voltages.

10.1 Selected Voltage Values — The technical committees can select a rated insulation voltage or system voltage from the voltage values given in Table 5.

The R10 series voltage values given in Table 3 are derived from Fig. 2 and the table includes values of typical system voltages. If necessary, technical committees can select other voltages.

Tables 4 and 5 are for the purpose of relating the voltage values of Table 3 to the most commonly used supply systems voltages.



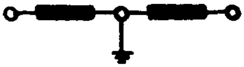
1. Withstand voltages for clearances according to Table 6.
2. Homogeneous field U impulse (1·2/50).
3. Homogeneous field U rms.
4. Inhomogeneous field U impulse (1·2/50).
5. Pollution degree 1.
6. Pollution degree 2.
7. Pollution degree 2 Material group 1.
8. Pollution degree 3 Material group 1.
9. Pollution degree 4 Material group 1.

NOTE — For the purpose of comparison, clearances are added.

FIG. 2 CREEPAGE DISTANCES, DEPENDENT ON VOLTAGE POLLUTION DEGREE, MATERIAL GROUP

TABLE 4 SINGLE-PHASE THREE OR TWO-WIRE AC OR DC SYSTEMS

(*Clause* 10.1)

Nominal Voltage of Supply System*	Voltage Reference for Table 3	
	Phase-to-Phase All Systems (Between Conductors of Different Polarity for dc) (*see* Note 1)	Phase-to-Earth 
(1)	(2)	(3)
V rms or dc	V rms or dc	V rms or dc
12·5	12·5	—
24 25	25	—
30	32	—
42 48 50†	50	—
60	63	—
60/30	63	32
100†	100	—
110 120	125	—
150†	160	—
220	250	—
220/110 240/120	250	125
300†	320	—
440/220	500	250
600†	630	—
960/480	1 000	500
1 000†	1 000	—

*This voltage can be the same as the rated voltage of the equipment.

†These values correspond to the values given in Table 1.

Note — Phase-to-earth insulation level for unearthed or impedanced earthed systems equals that for phase-to-phase because the operating voltage to earth or any phase may, inpractice, approach full phase voltage. This is because the actual voltage to earth is determined by the insulation resistance and capacitative reactance of each phase to earth; thus, low (but acceptable) insulation resistance on one phase may in effect earth it and raise the other two to full phase volts above earth.

11. MEASUREMENT OF CREEPAGE DISTANCES AND CLEARANCES

11.0 The widths X of grooves specified in Fig. 3, Examples 1 to 11 basically apply to all examples as a function of pollution degree as follows:

Pollution Degree	*Minimum Values of Width X of Grooves*
1	0 25 mm
2	1·0 mm
3	1·5 mm
4	2·5 mm

NOTE — If the associated clearance distance is less than 3 mm, the minimum groove width may be reduced to one-third of this clearance distance.

The methods of measuring creepage distances and clearances to be used in interpreting the requirements of this report are indicated in Examples 1 to 11. These cases do not differentiate between gaps and grooves or between types of insulation.

The following assumptions are made:

a) Any corner is assumed to be bridged with an insulating link of X mm width moved into the most unfavourable position (*see* Example 3).

b) Where the distance across the top of a groove is X mm or more, a creepage distance is measured along the contours of the grooves (*see* Example 2).

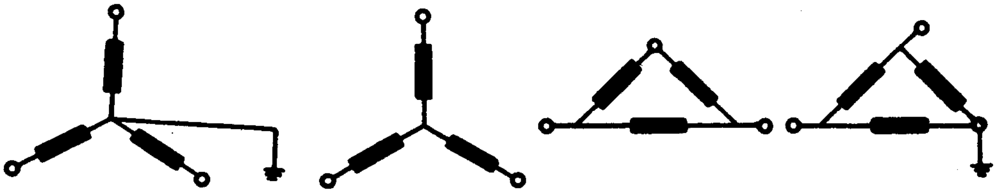
c) Creepage distances and clearances measured between parts moving in relation to each other are measured when these parts are in their most unfavourable positions.

12. DIMENSIONING PROCEDURE

12.1 Examples of dimensioning procedure for clearances and creepage distances according to this Guide are given in Appendix D.

TABLE 5 THREE-PHASE FOUR- OR THREE-WIRE AC SYSTEMS

(*Clause* 10.1)



NOMINAL VOLTAGE OF SUPPLY SYSTEM* rms in volts	VOLTAGE REFERENCE FOR TABLE 3		
	Phase-to-Phase All Systems (*see* Note 1)	Phase-to-Earth	
	rms in volts	rms in volts (*see* Note 2)	rms in volts (*see* Note 1)
(1)	(2)	(3)	(4)
60	63	32	63
110 120 127	125	80	125
150†	160	—	160
208	200	125	200
220 230 240	250	160	250
300†	320	—	320
380 400 415	400	250	400
440	500	250	500
480 500	500	320	500
575	630	400	630
600†	630	—	630
660 690	630	400	630
720 830	800	500	800
960	1 000	630	1 000
1 000	1 000	—	1 000

*This voltage can be the same as the rated voltage of the equipment.

†These values correspond to the values given in Table 1.

NOTE 1 — Phase-to-earth insulation level for unearthed or impedanced earthed systems equals that for phase-to-phase because the operating voltage to earth or any phase may, in practice, approach full phase voltage. This is because the actual voltage to earth is determined by the insulation resistance and capacitative reactance of each phase to earth; thus, low (but acceptable) insulation resistance on one phase may in effect earth it and raise the other two to full phase volts above earth.

NOTE 2 — In those countries where both star and delta, earthed and unearthed supply systems are used, the values for delta systems only should be used.

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TABLE 6 WITHSTAND VOLTAGES IN KILOVOLTS FOR AN ALTITUDE OF 2 000 m ABOVE SEA LEVEL

(*Clauses* 5.4.0 *and* 7.1)

CLEARANCE	CASE A INHOMOGENEOUS FIELD			CASE B HOMOGENEOUS FIELD	
	ac (50/60 Hz)		Impulse (1·2/50)	ac (50/60 Hz)	ac (50/60 Hz) and Impulse (1·2/50)
mm	*U* rms	$\overset{\triangle}{U}$	$\overset{\triangle}{U}$	*U* rms	$\overset{\triangle}{U}$ and $\overset{\triangle}{U}$ impluse
(1)	(2)	(3)	(4)	(5)	(6)
0·010	0·23	0·33	0·33	0·23	0·33
0.012	0·25	0·35	0·35	0·25	0·35
0·015	0·26	0·37	0·37	0·26	0·37
0·020	0·28	0·40	0·40	0·28	0·40
0·025	0·31	0·44	0·44	0·31	0·44
0·030	0·33	0·47	0·47	0·33	0·47
0·040	0·37	0·52	0·52	0·37	0·52
0·050	0·40	0·56	0·56	0·40	0·56
0·062 5	0·42	0·60*	0·60*	0·42	0·60*
0·080	0·46	0·65	0·70	0·50	0·70
0·10	0·50	0·70	0·81	0·57	0·81
0·12	0·52	0·74	0·91	0·64	0·91
0·15	0·57	0·80	1·04*	0·74	1·04
0·20	0·62	0·88	1·15	0·89	1·26
0·25	0·67	0·95	1·23	1·03	1·45
0·30	0·71	1·01	1·31	1·15	1·62
0·40	0·78	1·11	1·44	1·38	1·95
0·50	0·84	1·19	1·55	1·59	2·25
0·60	0·90	1·27	1·65	1·79	2·53
0·80	0·98	1·39	1·81	2·15	3·04

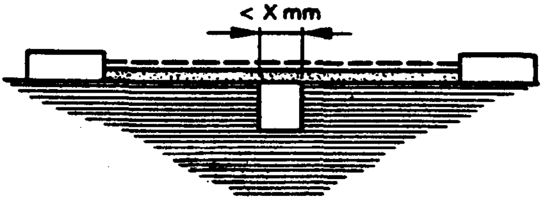
(*Continued*)

TABLE 6 WITHSTAND VOLTAGES IN KILOVOLTS FOR AN ALTITUDE OF 2 000 m ABOVE SEA LEVEL — *Contd*

CLEARANCE	CASE A INHOMOGENEOUS FIELD			CASE B HOMOGENEOUS FIELD	
	ac (50/60 Hz)		Impulse (1·2/50)	ac (50/60 Hz)	ac (50/60 Hz) and Impulse (1·2/50)
mm	*U* rms	$\hat{U}$	$\hat{U}$	*U* rms	$\hat{U}$ and $\hat{U}$ impulse
(1)	(2)	(3)	(4)	(5)	(6)
1·0	1·06	1·50*	1·95	2·47	3·50*
1·2	1·20	1·70	2·20	2·89	4·09
1·5	1·39	1·97	2·56	3·50	4·95
2·0	1·68	2·38	3·09	4·48	6·33
2·5	1·96	2·77	3·60	5·41	7·65
3·0	2·21	3·13	4·07	6·32	8·94
4·0	2·68	3·79	4·93	8·06	11·4
5·0	3·11	4·40	5·72	9·76	13·8
6·0	3·51	4·97	6·46	11·5	16·2
8·0	4·26	6·03	7·84	14·6	20·7
10·0	4·95	7·00*	9·10	17·7	25·0*
12·0	5·78	8·18	10·6	20·9	29·6
15·0	7·00	9·90	12·9	25·7	36·4
20·0	8·98	12·7	16·4	33·5	47·4
25·0	10·8	15·3	19·9	41·2	58·3
30·0	12·7	17·9	23·3	48·8	69·0
40·0	16·2	22·9	29·8	63·6	90·0
50·0	19·6	27·7	36·0	78·5	111·0
60·0	22·8	32·3	42·0	92·6	131·0
80·0	29·2	41·3	53·7	120·9	171·0
100·0	35·4	50·0*	65·0	148·5	210·0*

NOTE — For simplification the statistical measured values according to this table are replaced by straight lines between the values marked "*" in double logarithmic diagram taking into account the correction factors from 0 to 2 000 m altitude. The intermediate values are taken from the diagram (*see* Fig. 6) so that they enclose the measured values with a small safety margin. The values of *U* rms are found by dividing the values of *U* by $\sqrt{2}$.

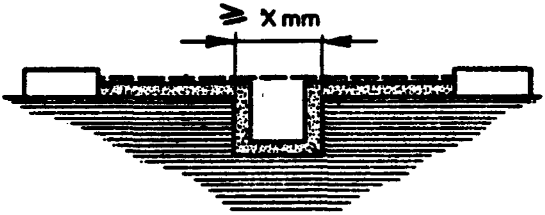
Example 1



Condition : Path under consideration includes a parallel- or converging-sided groove of any depth with a width less than X mm.

Rule : Creepage distance and clearance are measured directly across the groove as shown.

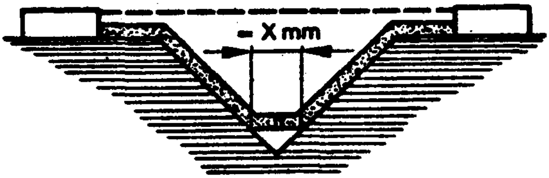
Example 2



Condition : Path under consideration includes a parallel-sided groove of any depth and equal to more than X mm.

Rule : Clearance is the "line of sight" distance. Creepage path follows the contour of the groove.

Example 3



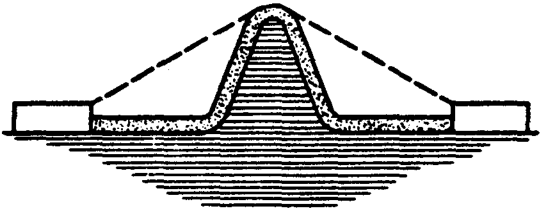
Condition : Path under consideration includes a V-shaped groove with a width greater than X mm.

Rule : Clearance is the "line of sight" distance, Creepage path follows the contour of the groove but "short-circuits" the bottom of the groove by X mm.

— — — — — Clearance ▨ Creepage distance

FIG. 3 METHODS OF MEASURING CLEARANCES AND CREEPAGES — *Contd*

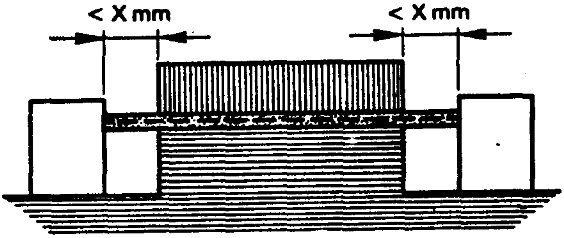
Example 4



Condition : Path under consideration includes a rib.

Rule : Clearance is the shortest direct air path over the top of the rib. Creepage path follows the contour of the rib.

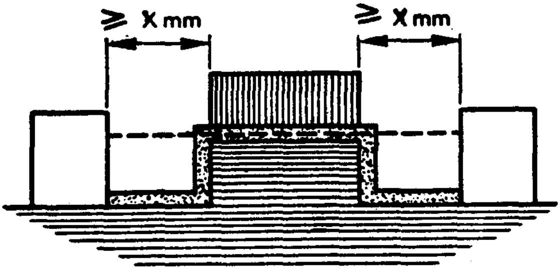
Example 5



Condition : Path under consideration includes an uncemented joint with grooves less than *X* mm wide on each side.

Rule : Creepage and clearance path is the "line of sight" distance shown.

Exnmple 6



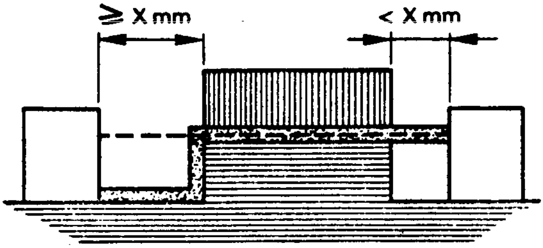
Condition : Path under consideration includes an uncemented joint with grooves equal to or more than *X* mm wide on each side.

Rule : Clearance is the "line of sight" distance. Creepage path follows the contour of the grooves.

— — — — — Clearance ▨ Creepage distance

FIG. 3 METHODS OF MEASURING CLEARANCES AND CREEPAGES — *Contd*

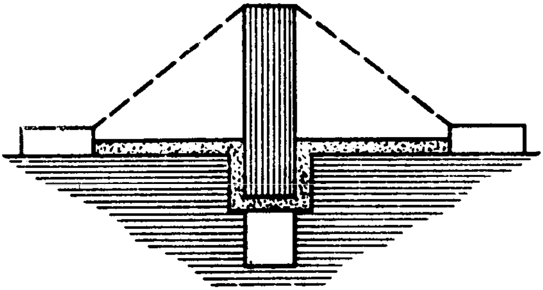
Example 7



Condition : Path under consideration includes an uncemented joint with a groove on one side less than *X* mm wide and the groove on the other side equal to or more than *X* mm wide.

Rule : Clearance and creepage paths are as shown.

Example 8



Condition : Creepage distance through uncemented joint is less than creepage distance over barrier.

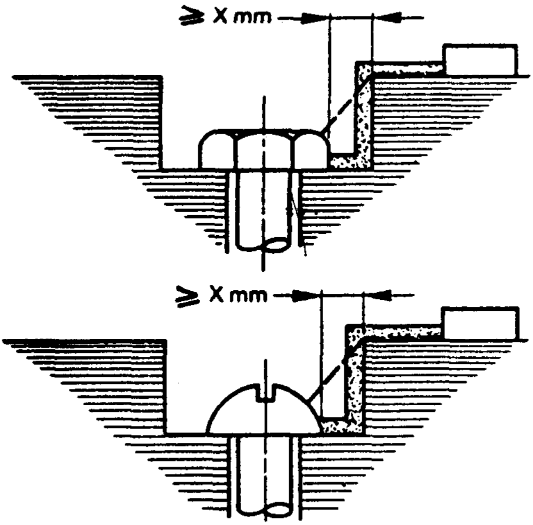
Rule : Clearance is the shortest direct air path over the top of the barrier.

— — — — — Clearance

▨ Creepage distance

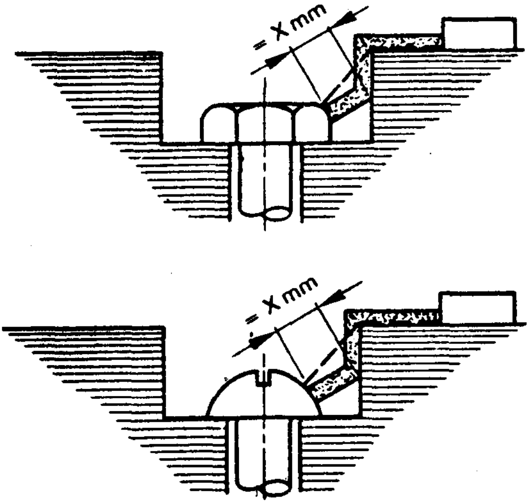
FIG. 3 METHODS OF MEASURING CLEARANCES AND CREEPAGES — *Contd*

Example 9



Gap between head of screw and wall of recess wide enough to be taken into account.

Example 10

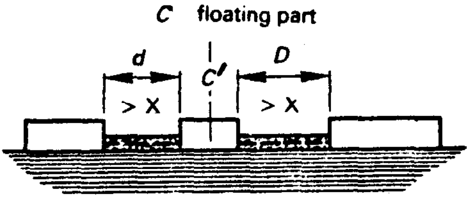


Gap between head of screw and wall of recess too narrow to be taken into account. Measurement of creepage distance is from screw to wall when the distance is equal to *X* mm.

— — — — — Clearance ▨ Creepage distance

FIG. 3 METHODS OF MEASURING CLEARANCES AND CREEPAGES — *Contd*

Example 11

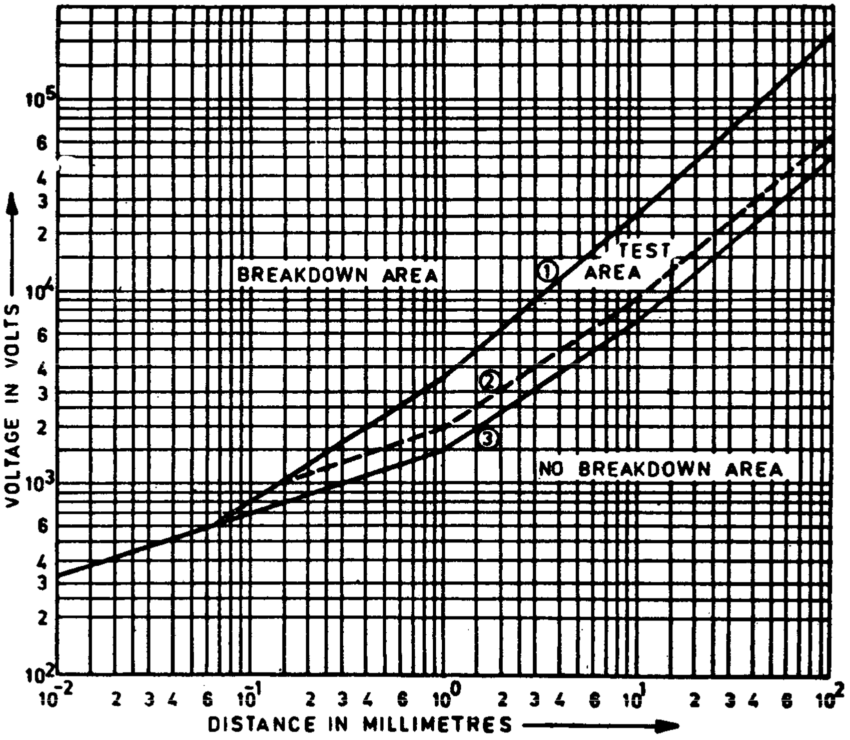


Clearance is the distance $d + D$.

Creepage distance is also $d + D$.

- - - - - Clearance ▨ Creepage distance

FIG. 3 METHODS OF MEASURING CLEARANCES AND CREEPAGES

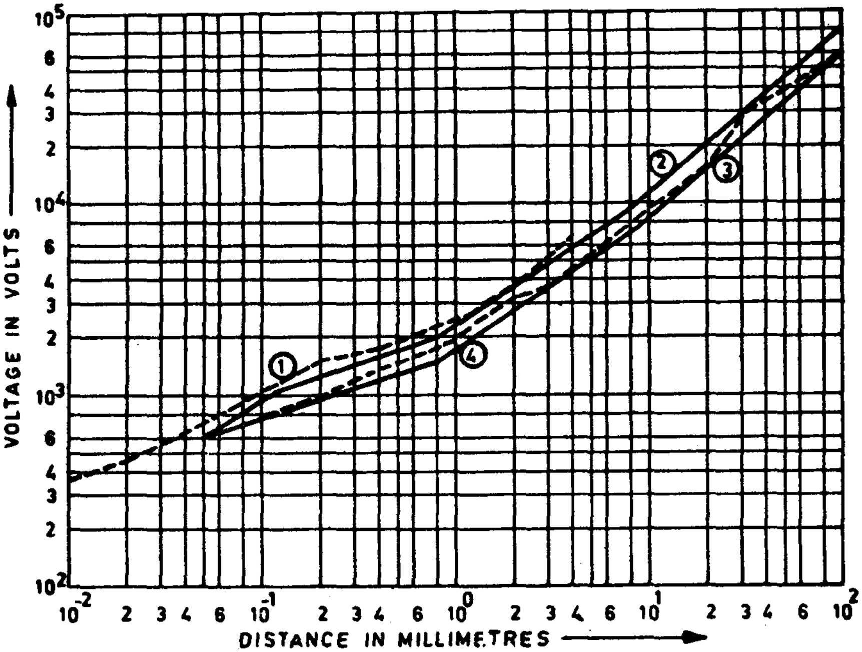


(1) Case B *U* 1·2/50 and *U* rms 50/60 Hz

(2) Case A *U* 1·2/50

(3) Case A *U* rms 50/60 Hz

FIG. 4 WITHSTAND VOLTAGE FOR AN ALTITUDE OF 2 000 m ABOVE SEA LEVEL



(1) U = 1·2/50

(2) Low limits for U = 1·2/50

(3) U = 50 Hz

(4) Low limits for U = 50 Hz

FIG. 5 EXPERIMENTAL DATA MEASURED AT APPROXIMATELY SEA LEVEL AND THEIR LOW LIMITS FOR INHOMOGENEOUS FIELD

TABLE 7 EXPERIMENTAL DATA

(*See* Fig. 5)

CLEARANCES IN AIR	INHOMOGENEOUS FIELD (POINT TO PLANE)				HOMOGENEOUS FIELD (SPHERE TO PLANE)		
	Breakdown voltages		Low limit voltages*		Breakdown voltages		Low limit voltages
mm	*U*-50 Hz	*U*-1·2/50	*U*-50 Hz	*U*-1·2/50	*U*-50 Hz	*U*-1·2/50	*U*-50 Hz and *U*-1·2/50
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0·010	—	360			360	360	
0·012	—	—			—	—	
0·015	—	—			—	—	
0·020	—	460			430	460	
0·025	—	—			—	—	
0·030	—	560			500	560	
0·040	—	640			580	640	
0·050	—	720	**600**	600	650	720	600
0·060	—	800	631	674	700	800	674
0·080	—	930	701	809	820	930	809
0·10	780	1 030	754	932	980	1 030	932
0·12	—	—	801	1 041	—	—	1 047
0·15	—	—	863	1 121	—	—	1 207
0·20	990	1 500	949	1 234	—	1 530	1 449
0·25	—	—	1 041	1 327	—	—	1 670
0·30	1 200	1 670	1 085	1 410	—	2 030	1 876
0·40	1 370	1 750	1 193	1 551	—	2 410	2 250
0·50	1 440	1 900	1 284	1 669	2 700	2 810	2 600
0·60	—	—	1 364	1 773	—	—	2 910
0·80	—	—	**1 500**	1 950	—	—	3 500
1·0	1 940	2 500	1 742	2 265	4 500	4 640	4 230
1·2	2 300	2 650	1 967	2 560	—	5 370	4 950
1·5	2 660	3 140	2 280	2 960	6 000	6 360	5 990
2·0	3 150	3 600	2 770	3 600	7 500	7 820	7 650
2·5	—	—	3 210	4 170	—	—	9 260
3·0	3 680	5 100	3 630	4 720	11 200	—	10 820
4·0	—	6 700	4 400	5 720	—	—	13 830
5·0	5 370	—	5 110	6 640	16 800	—	16 740
6·0	—	—	5 770	7 500	—	—	19 560
8·0	7 920	—	**7 000**	9 100	26 000	—	25 000

*Low limit voltage *U*-1·2/50 = 1·3 × *U*-50 Hz above 0·12 mm.

(*Continued*)

TABLE 7 EXPERIMENTAL DATA — *Contd*

CLEARANCES IN AIR	INHOMOGENEOUS FIELD (POINT TO PLANE)				HOMOGENEOUS FIELD (SPHERE TO PLANE)		
	Breakdown voltages		Low limit voltages*		Breakdown voltages		Low limit voltages
mm	*U*-50 Hz	*U*-1·2/50	*U*-50 Hz	*U*-1·2/50	*U*-50 Hz	*U*-1·2/50	*U*-50 Hz and *U*-1·2/50
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
10·0	9 480	—	8 470	11 010	31 700	—	30 700
12·0	10 900	—	9 900	12 870	—	—	36 400
15·0	12 600	—	11 970	15 560	45 500	—	44 700
20·0	15 600	—	15 310	19 900	59 000	—	58 300
25·0	22 000	—	18 520	24 100	—	—	71 700
30·0	27 600	—	21 600	28 100	86 000	—	84 800
40·0	33 900	—	27 700	36 000	112 000	—	110 700
50·0	38 900	—	33 500	43 600	138 000	—	136 000
60·0	43 100	—	39 100	50 800	164 000	—	161 000
80·0	52 300	—	**50 000**	65 000	215 000	—	210 000

*Low limit voltage *U*-1·2/50 = 1·3 × *U*-50 Hz above 0·12 mm.

NOTE 1 — Experimental data in volts measured at approximately sea level and their low limits. The values are obtained under ultra violet exposure.

NOTE 2 — Values in bold show breakpoints of line 4 in Figure 5.

APPENDIX A

(*Clauses* 1.3, 5.1, 5.2, 5.4.0 and 7.1)

ALTITUDE CORRECTION FACTORS

A-0. Paschen's Law — The Paschen's law states that at a constant temperature and above the critical pressure the breakdown voltage is a function only of the product of the gas pressure and the distance between parallel plane electrodes. Values of multiplication factor, corresponding to the pressures at different altitude are as follows:

Altitude m	*Normal Barometric Pressure* kPa	*Multiplication Factor for Distance*
0	101·3	0·79
500	95·0	0·84
1 000	90·0	0·89
2 000	80·0	1·00
3 000	70·0	1·14
4 000	62·0	1·29
5 000	54·0	1·48
6 000	47·0	1·70
7 000	41·0	1·95
8 000	35·5	2·25
9 000	30·5	2·62
10 000	26·5	3·02
15 000	12·0	6·67
20 000	5·5	14·5

A-1. Conduction Through a Gas — The conduction through a gas may be initiated in different forms classified as follows:

a) Corona,
b) Glow dischage,
c) Spark, and
d) Arc.

One form may give place to another in quick succession, depending upon attendant conditions. Arc formation depends upon the presence of an electric field which tends to strip electrons from the positively charged nuclei of the atoms of the gas between electrodes. Under the right conditions, these electrons collide with other electrons and release them from their atomic bonds in a cascading fashion. The net result is a flow of electrons, that is, electric current and arc discharge.

A-2. Dielectric Breakdown of a Gas — The dielectric breakdown of a gas in a uniform electric field depends upon the product of the gas pressure and the electrode spacing (Paschen's law) for a given gas mixture, electrode shape and material. The peak value of the minimum sparking potential (U) for some gases is as follows:

Air	327 V	Carbon dioxide (CO_2)	419 V
Nitrogen (N_2)	251 V	Helium (H_e)	156 V
Hydrogen (H_2)	273 V	Acetylene (C_2H_2)	468 V
Oxygen (O_2)	439 V	Sulphur dioxide (SO_2)	457 V

APPENDIX B

(*Clause* 3.8.1)

MEANS FOR TRANSIENT OVERVOLTAGE CONTROL (SURGE ARRESTER DEVICES)

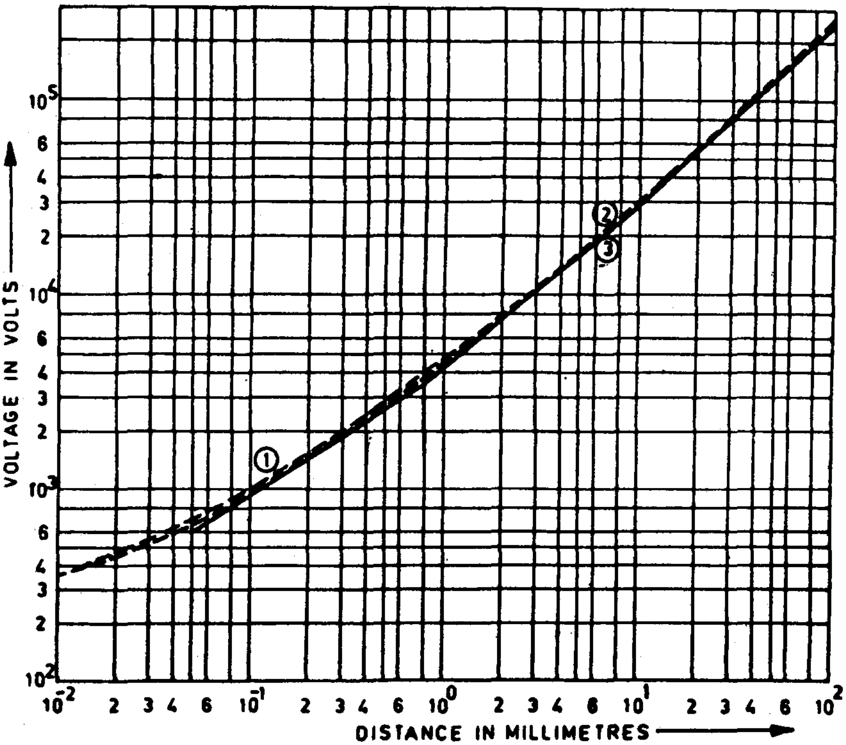
B-0. For the purpose of this Guide, surge arrester devices are to protect given clearance values from sparkovers which may be caused by overvoltages.

From Appendix A, it can be seen that a clearance in air will withstand a standard 1·2/50s impulse, depending solely upon the electrode configuration and air pressure.

B-1. Table 2 shows the most unfavourable Case A, that is, the most non-uniform electric field conditions, and the most favourable Case B, that is, the most uniform electric field conditions to withstand given values of impulse voltages.

Conversely, Table 3 shows withstand values of impulse voltages for Case A and Case B electric field conditions for given values of clearance. Corresponding rms and peak values of voltage are also given.

It follows, then, that every clearance is actually a spark-gap device, and that each clearance has an impulse withstand voltage capability ranging from Case A to Case B values, dependent solely upon electrode configuration (at a given air-pressure or altitude).



(1) $U = 1{\cdot}2/50$

(2) $U = 50$ Hz by Paschen

(3) Low limits for $U = 50$ Hz and $U = 1{\cdot}2/50$

FIG. 6 EXPERIMENTAL DATA MEASURED AT APPROXIMATELY SEA LEVEL AND THEIR LOW LIMITS FOR HOMOGENEOUS FIELD

B-2. It is, therefore, evident that clearances sparkover when impulse voltages exceed the impulse withstand voltage capability. In electrical systems having no specific surge arresters for the purpose of preventing sparkovers, clearances sparkover when the withstand voltage capability is exceeded. The result of sparkover may be insignificant or catastrophic depending upon the amount of impulse energy to be dissipated, the power frequency voltage, and the available power follow current, etc. The follow current resulting from a sparkover may also affect the performance of insulation materials.

The simple spark gap in air, or clearance, can be used as a surge arrester to protect other clearances from sparkover due to overvoltages, when used within its limitations.

B-3. The occurrence of power-follow-current due to an impulse voltage sparkover is unpredictable, as it depends upon the time relationship of the impulse sparkover and the power current in the circuit, the ionization present between electrodes due to the impulse sparkover, the configuration of the electric field between the electrodes, the electrode material as well as the surge impedance characteristic of the circuit.

Another practical consideration is the breakdown voltage of the air gap. From Table 2 it can be seen that the minimum peak value of impulse voltage is 330 V, for a 0·01 mm gap. This is a rather impractical design criteria. A more practical minimum dimension might be 0·5 mm, which will withstand 1 500 V impulse. Therefore, if small values of clearance less than 0·5 mm are to be protected, the simple air-gap might be impractical.

APPENDIX C

(*Clause* 4.0)

APPLICATION GUIDE FOR CLEARANCES AND INSULATION CO-ORDINATION BASED ON CLEARANCE

C-1. There are several ways in which technical committees may use the recommendations and data presented in this report.

A rated impulse withstand voltage may be established for all present equipment based on the clearances used, by reference to Case A, in Table 2. A technical committee may alternatively establish a rated impulse withstand voltage for equipment using controlled design parameters and production techniques by specifying testing with an appropriate impulse test.

The technical committee should consider the transient overvoltage conditions to which the products will be subjected.

C-2. When transient overvoltages are controlled in the electrical system at the location where the product will be connected, the controlled value becomes the value or at least the minimum value of rated impulse withstand voltage for the product line.

When transient overvoltages are not controlled in the system, the technical committee should consider the consequence of the appearance of transient overvoltages in excess of the rated impulse withstand voltage. Consideration should be given to the provision of or the specification of the use of voltage limiting means at the line terminals of the equipment. It should be recognized that in some circumstances a clearance between conductive parts may be used as a transient overvoltage limiting means, if the clearance and the electrodes are appropriately evaluated.

C-3. The technical committee may utilize clearances from Table 2 based on the control of transient overvoltages within the equipment, either those coming from the supply circuit or those generated within the equipment. If desired the technical committee may utilize the complete series of values, with interpolation, given in Table 2, or alternatively, impulse withstand or equivalent ac (rms) withstand tests as defined in Appendix A may be used to confirm the presence of adequate clearances. dc withstand test voltages may be considered to be same as the peak ac values given under Case A in Appendix A.

APPENDIX D

(*Clause* 12.1)

EXAMPLE OF DIMENSIONING PROCEDURE FOR CLEARANCES AND CREEPAGE DISTANCES

D-0. In order to achieve insulation co-ordination within an equipment or an electrical system, initial conditions need to be stated from which decisions are made to determine minimum clearances, creepage distances and nameplate marking, where appropriate.

Initial conditions to be stated by the technical committee and/or the manufacturer:

- rated voltage, rated insulation voltage or working voltage (*see* **2.3**, **2.4** and **2.7**);

— installation category (location of equipment within an electrical system) (Figure 1);

— pollution degree (*see* **5.3.1**).

The following procedure is suitable only for operational or basic insulation.

D-1. DERIVED CONDITIONS

Step 1 — From the equipment nominal voltage of the supply system, determine the corresponding voltage reference value, phase-to-earth, from Table 6 or 7.

Step 2 — Using the phase-to-earth reference voltage derived in Step 1 and the stated installation category, determine the rated impulse withstand voltage from Table 1. Use the nearest higher phase-to-earth voltage value given in Table 1. For equipment having several installation categories, determine the lowest and highest impulse withstand voltages.

Step 3 — Using the highest rated impule withstand voltage from Step 2 and the stated pollution degree, determine the Cases A and B clearances from Table 2.

Step 4 — From the equipment nominal voltage of the supply system, determine the corresponding voltage reference value, phase-to-phase, from Table 6 or 7.

Where the working voltage across the insulation is known, that voltage can be used in Step 5.

Step 5 — Using the voltage reference values from Step 1 and Step 4 or the working voltage, the stated pollution determine the creepage distances from Table 5 for the appropriate material group.

The material group is decided by the equipment manufacturer.

Step 6 — Check the minimum creepage distances with associated clearances. The creepage distance shall be not less than the associated Case A clearance (with the exception, *see* **9.1**, second paragraph).

Identifying Data — For insulation co-ordination, the rated insulation voltage (*see* **2.4**) and the rated impulse withstand voltage (*see* **2.5**) are required.

Technical committees should decide whether identifying data is to be made available with the equipment or in relevant specifications.

Where complete marking is appropriate, the nominal voltage(s) of supply system for which the equipment is intended is (are) the *first number(s)* stated and the corresponding rated impulse withstand voltage(s) is (are) the *second number(s)* stated.

Example 1: *220/380/6 kV*

Explanation of Example 1 — The first numbers, *220/380*, indicate that the creepage distance to earth is appropriate for 220 V and between phases for 380 V and the equipment is suitable for a four-wire earthed neutral system of supply. The *second number, 6 kV,* is the rated impule withstand voltage of the equipment. The combination of 220 V to earth and 6 kV impulse withstand voltage indicates equipment suitability for installation category IV (*see* Table 1).

Example 2: *220/380 / 2·5-6 kV*

Explanation of Example 2 — The *first numbers* have the same meaning as in example 1. The *second numbers, 2·5-6 kV,* indicate that the equipment has a 6 kV impulse withstand voltage and will not generate overvoltages in excess of 2·5 kV (*see* **3.6**). The combination of 220 V to earth and 2·5-6 kV impulse withstand voltages indicates equipment suitability for installation categories II, III and IV (*see* Table 1).

NOTE — In addition, in some instances, it may be desirable for the manufacturer to state the rated insulation voltage(s) (*see* **2.4**). In the examples above, this would be 250 V phase-to-earth and 400 V phase-to-phase (*see* Tables 7 and 5).

D-3. A dimensional procedure worksheet, useful for recording the dimensional procedure decisions is given in Table 8.

Table 8 is a worksheet useful for recording the dimensioning procedure decisions under stated initial conditions for specified equipment.

In addition, Table 8 has space provided to record empirical data recording clearance and creepage distances. Comparison of empirical data with the minimum values determined from the dimensioning procedure will enable evalution of past and present practice with clearances and creepage distances determined for a coordinated insulation system.

TABLE 8 DIMENSIONING PROCEDURE WORKSHEET

(*Clause* D-3)

Equipment (1)	Parameters Voltage Distances (2)	Value (3)	Source (4)
Stated conditions (*ses* Note 1)	Nominal voltage of supply system (rated voltage) or working voltage	—	Rating plate or manufacturer's data
	Installation category		Fig. 1
	Pollution degree		5.3.1
Derived coditions	Clearances for:		
Step 1	Phase-to earth voltage		Table 1
Step 2	Rated impulse withstand voltage		2.5 and Table 1
Step 3	Clearance case A Clearance case B		Table 2 Table 2
Step 4	Voltage reference value: Phase-to-earth Phase-to-phase	—	Table 6 or Table 7
Step 5	Creepage distance for: Material group I Phase-to-earth Phase-to-phase	—	Table 5 and 9.4.2
	Material group II Phase-to-earth Phase-to-phase	—	9.4.2
	Material group IIIa Phase-to-earth Phase-to-phase	—	9.4.2
	Material group IIIb Phase-to-earth Phase-to-phase	—	9.4.2
Step 6	Check minimum creepage distance case A clearance for each material group		
	Identifying data (name plate)		According to specification of the Technical Committee
Empirical data	Clearance		
	Creepage distance		

NOTE 1 — Identical stated initial conditions must be assumed in order to make valid comparisons.

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

Quantity	*Unit*	*Symbol*
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Quantity	*Unit*	*Symbol*	*Definition*
Force	newton	N	1 N = 1 kg.m/s^2
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2

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